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Study of Fault Diagnosis Method Based on Data Fusion Technology

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Abstract

The method based on data fusion fault diagnosis is put forward and the two-step fusion diagnosis model of neural network and D-S evidence theory is given against the complexity and multiplicity when the fault of control system happens; the fault detection laboratory platform is erected based on the data fusion through the analysis of the electric actuator's principle and typical faults, and on this basis, the fault of the electric actuator is diagnosed by the experiment and computer simulation. This method overcomes the uncertainty of the neural network fault diagnosis and improves the accuracy of system diagnosis, and the experiment result verified the method's validity.

Keywords： data fusion; fault diagnosis; electric actuator;neural network.

1. Introduction

The automatic level is improving continuously along with the development of the industry control system, especially the modernized production process such as the large-scale heat-engine plant, whose controlling system includes hundreds of control loop. The faults of sensors and actuators are the main reasons which lead to the inactivation of the control system; particularly some important faulty signals drop the control quality rapidly and fail the control, and even cause such catastrophic consequence as damaging the equipment and tripping out. Statistics indicate that 80% control system inactivation is

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caused by the sensors and the electric actuators' faults [1,2], in these cases, the control system's fault diagnosis has decisive significance.

At present, the data fusion technology based on evidence theory is applied in the fault diagnosis broadly and is testified to be an effective algorithm. But this algorithm needs the probability assignment, which is a condition hard to meet in the practice[3,4]. In order to diagnose the electric actuator fault, a fusion algorithm is put forward which combines the artificial neural network and the improved evidence theory.

2. D-S (Demper-Shafer) Evidence Theory

Let $\Omega = \{\omega_1, \cdots, \omega_c\}$ be a frame of discernment, 2^{Ω} is the power set composes of all possible of subsets of Ω. Classes in Ω are assumed to be mutually exclusive and exhaustive. A function $m: 2^{\Omega} \to [0,1]$ is called a mass function, if $\sum_{A \subseteq \Omega} m(A) = 1$, and $m(\Phi) = 0$, Φ denotes an empty set. Subset A with non-zero mass is called a focal element (focal for short). Focal elements and their masses constitute an evidence structure, expressed in the form: $\{(A, m(A) \mid A \subseteq \Omega, m(A) > 0\}$. $(A, m(A))$ is referred to as a piece of evidence. The value of $m(A)$ represents the degree of evidential support with which a specific element of Ω belongs to the exact set A, not to subsets of A.

The two pieces of data are denoted by the proposition's belief degree and plausibility degree. For all the $A \subseteq \Omega$, there are the following definitions:

$$Bel(A) = \sum_{B \subseteq A} m(B) \tag{1}$$

$$Pl(A) = 1 - Bel(\bar{A}) = \sum_{B \cap A \neq \Phi} m(B) \tag{2}$$

$Bel(A)$、$Pl(A)$ and $Bel(\bar{A})$ are belief function, plausibility function and negative function of proposition A.

This combination rules of the evidence theory is the following: Let m_1 and m_2 is the basic probability assignment on 2^{Ω} which is mutually independent, the focal element is $A_1, \cdots, A_k$ and $B_1, \cdots, B_r$,

$$m(C) = \begin{cases} \dfrac{\sum_{\substack{i,j \\ A_i \cap B_j = A}} m_1(A_i) m_2(B_j)}{1 - K_1} & \forall C \subset \Omega and\ C \neq \phi \\ 0 & C = \phi \end{cases} \qquad \left(K_1 = \sum_{\substack{i,j \\ A_i \cap B_j = \phi}} m_1(A_i) m_2(B_j) < 1 \right) \tag{3}$$

3. Two-Step Fusion Diagnosis Algorithm

The two-step fusion diagnosis algorithm block diagram is the fig.1. The electric actuator's fault diagnosis system of the cascade control system includes three modules: data level fusion module, neural network diagnosis module and D-S evidence theory fusion diagnosis module. At first, the data collected in the field engineering gets into the faults diagnosis module in the computer after A/D transformation, and each sensor's characteristic signal is gotten, then the characteristic signal is sent into the neural network diagnosis module. The well trained network classed the fault pattern and identified initiatively by use of the diagnosis inference knowledge accumulated in the network structure, weight value and threshold value, the signal is mapped into various faults basic probability assignment value by the neural network, the gets into the D-S evident theory fusion module to fuse at the final step, and the fusion result

combines the expert knowledge to judge the system's operating state, if there is some fault, the corresponding process order is sent out.

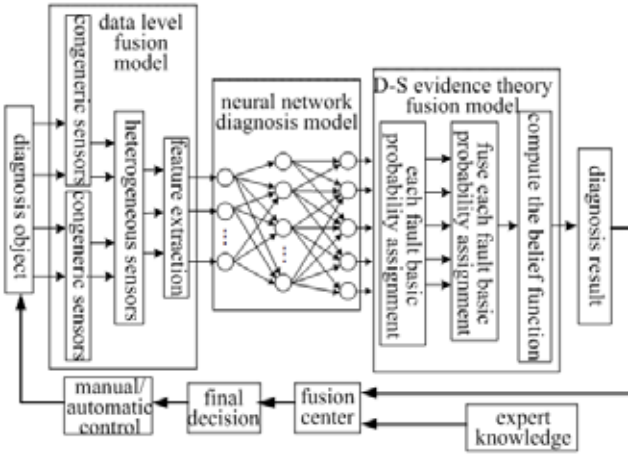

Fig.1. two-step fusion fault diagnosis system diagram

4. The Fault Analysis of the Electric Actuator

The mathematical model of the actuator[5,6] (ignoring the dynamic state) is: $y = \alpha \cdot x + \beta$. x and y is the input and output of the actuator; α and β is the gain coefficient and zero deviation of the actuator. Form the mathematical model of the electric actuator, there are two fault sources, namely α and β. α and β has different value according to different fault styles, which showed in the fig. 2. In the figure, line b and c is corresponded with one kind fault of the actuator in the rectangular range.

(1)Line a ($\alpha = 1, \beta = 0$) denotes that the actuator's normal working.

(2)Line b ($\alpha \neq 1$) denotes the mutant or slowly variable gain of the actuator, which are common in the object. If $\alpha = 0$, it shows the actuator's lock fault.

(3)Line c ($\beta \neq 0$) denotes the constant deviation fault of the actuator.

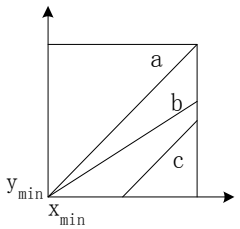

Fig. 2. fault diagrammatic sketch

It is clear in the fig.3 that there is deviation between the input and output of the actuator. When there is constant deviation fault of the actuator, the expression is that the feedback signal can't change along with the order signal's variation: the deviation of order signal and feedback signal exceeds the dead area range, and the deviation is on some fixed value.

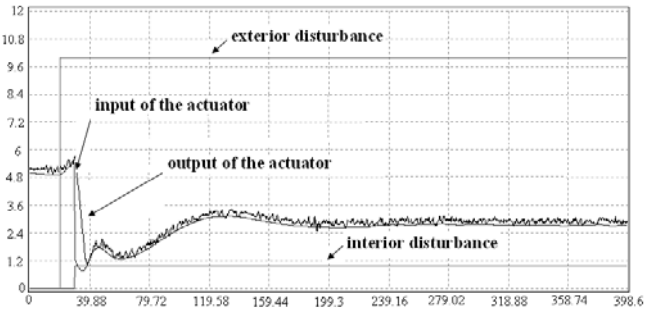

Fig.3. constant deviation fault curve

5. Fault Diagnosis Combined Neural Network and D-S Evidence Theory

The initiative result of the neural network is put into D-S evidence theory fusion center, which is fused with the improved fusion rule, and the result is denoted by the symbol '*' in fig. 4.

(1) The result of fig. 4-a is {1,0,0,0,0}, according to the rule of the probability maximal value, this result belongs to the first consequence, namely the normal state.

(2) The result of fig. 4-b is {0,1,0,0,0}, according to the rule of the probability maximal value, this result belongs to the second consequence, namely the dead area too big.

(3) The result of fig. 4-c is {0,0,1,0,0}, according to the rule of the probability maximal value, this result belongs to the third consequence, namely the constant gain fault.

(4) The result of fig. 4-d is {0,0,0,1,0}, according to the rule of the probability maximal value, this result belongs to the forth consequence, namely the constant deviation fault.

It is easy to make out from the figures that the last fusion result cancels the indeterminacy of the neural network initiative diagnosis result, and the accuracy result can be got, which verify the two-step fusion approach can identify the faults accurately, and this can direct the operating personnel's manipulation. From the figure, the following results can be gotten.

6. Conclusions

In the complex control system, the character of the controlled plant is nonlinear and time-variant, with a rather large disturbance, fuzzification and uncertainty and so on. Hence the system's fault symptom represents complexity, multivariant and diversity, and there is no obvious corresponding relation between them, the only simple theory method or single sensor data can't diagnose the faults accurately. The application of multi-sensor data fusion is more useful than the single sensor when describing, analysing and processing the system's problem, and can deal with various uncertainty relations and the relationship among various data sources. This paper takes the electric actuator as the research object, puts forward a kind of fault diagnosis method, i.e., the fusion fault diagnosis method that combines the neural network and D-S evidence theory, which fits the thermal control system. When this method is applied in the fault detection and diagnosis system design of the practical electric actuator, a better result is got, which proves the method's utility value.

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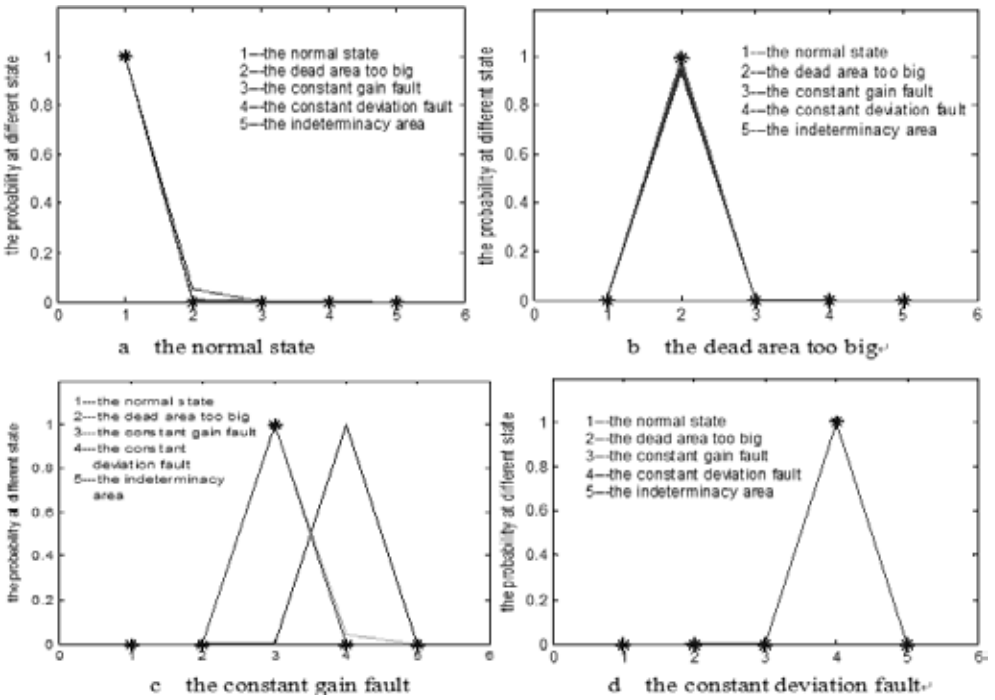

Fig.4. two-step fusion fault diagnosis output result

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